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14. ABSTRACT The technical report focus on the program and on the major scientific achievements of the 6th Time Scale Algorithm Symposium and Tutorials. The development and testing of new tools adequate for the mathematical treatment of the time measurements is the core of the organized Symposium. The huge impact of the availability of the PFS (running continuously) is a key issue of time scale algorithms. The Kalman filter applied to the construction of national and international timescales has been discussed. A large part of the conference was dedicated to the algorithms used for data analysis. In time keeping area typical problems are data gaps, outliers, jumps or clock failure identification.					
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# Technical Report on the 6<sup>th</sup> Time Scale Algorithm Symposium and Tutorials

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The 6th Time Scale Algorithm Symposium and Tutorials taken place at the Pavillon de Breteuil, BIPM (Sèvres, France) on 9-11 September, 2015.

The web page <http://www.bipm.org/en/conference-centre/bipm-workshops/tsas/> has been created to inform people about registration (including the registration fees), to distribute Tutorials and Symposium agendas and for downloading the presentations after the conference.

70 registered people, including 4 students, coming from more than 30 different countries participated to the 3 days of conference.

The Tutorials (the complete agenda is reported in the Annex A of this report) included 8 lectures on the basic mathematical and statistical algorithms in the field of time and frequency.

The first session was dedicated to time scales with lectures presenting a general introduction to the timescales (Dr. Demetrios Matsakis), an overview on the algorithms for national (Dr. Daniele Rovera) and international timescales (Dr. Gianna Panfilo). The use of the algorithms in different fields of time and frequency metrology was highlighted by lectures on timekeeping and space navigation systems (Dr. Patrizia Tavella).

The second session was dedicated to the basic tools for time scales with lectures deal with State Space Control (Dr. Paul Koppang) and with the application of the Kalman Filter on Time Scales (Dr. Michael Coleman). Algorithms for the Global Navigation Satellite System time transfer (Dr. Pascale Defraigne) and for supporting time transfers by means of digital networks (Dr. Judah Levine) are also presented during the second session of the Tutorials.

The Symposium (the complete agenda is reported in the Annex B of this report) includes 4 invited presentations, Dr. Urs Hugentobler with the presentation “Clock Corrections from GNSS”, Dr. Bill Coles with “Algorithms for Development of a Pulsar-based Time-scale”, Dr. Goran Peskir on the “Optimal Stopping” and Dr. Poul-Henning Kamp on the “Improved NTP Timekeeping”.

The Symposium includes also 25 contributions on different topics grouped on 7 different sessions:

- National time scale algorithms – the state of the art of the current time scale algorithms is presented
- Time scale with primary frequency standards – the role of the primary frequency standards is highlighted in the time scale building
- Clock estimation and space system – the presentations focused on the algorithms for GNSS system
- Pulsar Time Scales – the algorithms for the development of a pulsar-based timescale are presented
- Anomalous behavior, correlation, missing data handling – general problems concerning the data treatment are discussed
- Kalman and Vondrak applications – the use of these powerful statistical tools is presented in timescale treatment
- NTP Algorithms – the improvements concerning the NTP timekeeping are presented.



From all the presentations and lectures given in the conference 6 are selected and encouraged for sending a paper to Metrologia in order to publish a small group of papers that Metrologia will bundle together.

## **Detailed Report**

The International Time Scale Algorithms Symposia and Tutorials have been organized at intervals of 5 to 7 years by the BIPM and different national institutes. These symposia constitute the unique international conference entirely dedicated to the key challenges for national and international timekeeping requesting for special mathematical handling. The tutorials give the opportunity to disseminate the new methods and application among young metrologists.

The time elapsed between these events allows the development and testing of new tools adequate for the mathematical treatment of the time measurements. Each symposium has the characteristic of opening venues to innovative methods.

The program of the VI International Time Scale Algorithms Symposia and Tutorials was designed for focusing on key issues of time scales algorithms.

The laboratories contributing to the generation of UTC are strongly concerned with the quality of the time scale they deliver, and consequently an important part of the conference was dedicated to the improvement on the algorithms used for the construction of the national time scales UTC(k). Different approaches have been presented at the symposium, in particular the time scales based on the use of primary frequency standards (PFS) and those based on very powerful mathematical tools as the case of the Kalman Filter.

The availability of a PFS running continuously has huge impact on the design of a time scale. Significant improvement occurred in term of long and short term stability performances by integrating the use of PFS in the time scale calculation. Considering the development of optical clocks in several laboratories first tests and studies have been presented on their use for time scale calculation. In particular the problem linked to the comparison of optical clocks with the current time links status.

The use of the Kalman filter has presented by showing the good results that can be obtained if all the parameters of this statistical tool are well controlled and evaluated. The particular application of the Kalman filter to the construction of national and international timescales has been discussed.

The BIPM has been regularly publishing in the last two years results of a rapid realization of UTC (called UTCr). Several presentations showed results obtained by developing new algorithms taking in to account the UTCr in the process for predicting and controlling their national time scales. The weekly publication of UTCr with respect to the monthly publication of UTC allows new studies and developments in order to maintain the national time scales close to UTC as presented by several laboratories.

A large part of the conference was dedicated to the algorithms used for data analysis. In space application as in time keeping area we are faced with typical problems like data gaps, outliers, jumps or clock failure identification. Real time algorithms for identifying and solving these anomalies are

necessary to make a correct statistical analysis and to improve the performance. Very innovative methods have been presented during the Symposium showing a large improvement of the stability of the atomic clock.

Theoretical mathematical research has been presented by introducing the optimal stopping theory. The application of this method for detecting clock frequency jumps has also been presented. This new algorithm succeeds in the detection of the frequency jumps by following a very formal mathematical theory. The use of the mathematics is highlighted in this presentation in perfect agreement with the idea of the Symposium.

A dynamical time scale based on pulsar observations has been developed by astronomers. This pulsar-based time scale is characterized by very long term stability, and could be complementary of the atomic time scale realized by metrology. This new approach has been presented and discussed at the symposium.

The symposium included the mathematical treatment necessary to modern time dissemination systems as Network Time Protocol (NTP). A session was devoted to showing the state of the art of the NTP timekeeping and the last studies and achievements for synchronize networked clocks.

## ANNEX A



### VI International Time Scale Algorithms Symposium and Tutorials

9 September 2015

#### Agenda of Tutorials

##### Session I

###### Time scales

09:50 – 10:00 Opening

10:00 – 10:45 Introduction to timescales, Dr. Matsakis, USNO

10:45 – 11:30 Algorithms for the international time scales UTC and UTCr, Dr. Panfilov, BIPM

11:30 – 11:50 *Tea/coffee break*

11:50 – 12:35 National Time Scales, Dr. Rovera, LNE-Syrté

12:35 – 13:20 Algorithms for Timekeeping and Space navigation systems, Dr. Tavella, INRIM

13:20 – 14:30 *Lunch*

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##### Section II

###### Basic tools for Time scales

14:30 – 15:15 State Space Control, Dr. Koppang, USNO

15:15 – 16:00 Applications of Kalman Filters to Time Scales, Dr. Senior/Dr. Coleman, NRL

16:00 – 16:20 *Tea/Coffee Break*

16:20 – 17:05 Algorithms for GNSS Time Transfer, Dr. Defraigne, ORB

17:05 – 17:50 Algorithms to support time transfers by means of digital networks, Dr. Levine, NIST

17:50 End of Tutorials

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*Funding for this symposium and tutorials comes from the generous financial support of NICT (National Institute of Information and Communications Technology - Japan) and ONRG (Office of Naval Research, Science & Technology, Global).*



## ANNEX B



### VI International Time Scale Algorithms Symposium and Tutorials

10-11 September 2015

#### Preliminary Agenda of Symposium

#### 10 September 2015 – Symposium

10:00    10:10    Opening

#### *SESSION I - National time scale algorithms*

10:10	10:30	Realization of the Swedish National Distributed Time Scale (Carsten Rieck, SP, Sweden)
10:30	10:50	Brazilian Atomic Time Scale TA(ONRJ) (Ricardo Josée de Carvalho, ONRJ, Brazil)
10:50	11:10	Algorithms for UTC(NIM) realization (Yuan Gao, NIM, China)

11:10 - 11:30    *Tea / coffee break*

11:30	11:50	Upgrading of UTC(NICT) (Yuko Hanado, NICT, Japan)
11:50	12:10	TA(SU) and UTC(SU) Maintenance in the Main Metrology Center of the State Service for Time and Frequency (Koshelyaevsky N., VNIIFTRI, Russia)
12:10	12:30	Steering UTC(TL) Toward The Cesium Clock Ensemble Time Scale of TL (Shinn Yan Lin, TL, Taiwan)
12:30	12:50	A UTC(IT) Steering Algorithm Based on an Atomic Clock Ensemble Scale (P. Tavella, INRIM, Italy)

12:50 - 14:10    *Lunch*

#### *SESSION II - Time scale with primary frequency standards*

14:10	14:30	Realization of UTC(OP) based on LNE-SYRTE atomic fountains (Daniele Rovera, LNE-SYRTE, France)
14:30	14:50	Rapid evaluation of time scale using an optical clock (Tetsuya Ido, NICT, Japan)
14:50	15:10	UTC(IT) steering algorithm relying on the ITCsF2 Primary Frequency Standard measurements (G. Signorile, INRIM, Italy)
15:10	15:30	A timescale based on the world's fountain clocks (G. Petit, BIPM, France)

15:30 - 16:00    *Tea / coffee break*

### **SESSION III - Clock estimation and space system**

16:00	16:40	Invited talk - Urs Hugentobler "Clock Corrections from GNSS"
16:40	17:00	An efficient and configurable preprocessing algorithm for robust clock data analysis (I. Sesia, INRIM, Italy)
17:00	17:20	Robust Clock Ensemble for Time and Frequency Reference System (Qinghua Wang Orolia Switzerland SA (Spectratime), Switzerland)
17:20	17:40	Galileo System Time Steering by the Time Validation Facility (TVF) (Roldán Pedro, GMV, Spain)

**18:15**                      ***Departure for Dinner***

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**11 September 2015 – Symposium**

### **SESSION IV – Pulsar time scales**

09:40	10:20	Invited talk – Bill Coles "Algorithms for Development of a Pulsar-based Time-scale"
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**10:20 - 10:50**    ***Tea / coffee break***

### **SESSION V - Anomalous behavior, correlation, missing data handling**

10:50	11:30	Invited Talk - Goran Peskir "Optimal Stopping"
11:30	11:50	Detection of atomic clock frequency jumps with an optimal stopping method (C. Zucca, University of Torino, Italy)
11:50	12:10	Multi-detection of anomalies in precise clocks for space applications (L. Galleani, Politecnico di Torino, Italy)
12:10	12:30	Impact of correlations on the uncertainties of [UTC-UTC(k)] (Panfilo Gianna, BIPM, France)
12:30	12:50	An adaptive algorithm to estimate the Allan Variance from clock frequency data with gaps and dead times (I. Sesia, INRIM, Italy)

**12:50 - 13:50**    ***Lunch***

13:50	14:10	Optical clock comparison with broadband two-way satellite time and frequency transfer (Franziska Riedel, PTB, Germany)
14:10	14:30	Dead time and missing data: the impact on frequency estimate and uncertainty (Signorile Giovanna, INRIM, Italy)

#### ***SESSION VI - Kalman and Vondrak applications***

<b>14:30</b>	<b>14:50</b>	Clock ensembling using Kalman filter -- implications of non-observability and causality (Marek Peca, Czech Technical University, Czech Republic)
<b>14:50</b>	<b>15:10</b>	An application of the Kalman Filter to UTC (F. Parisi, University of Torino/BIPM, Italy)
<b>15:10</b>	<b>15:30</b>	Vondrak Smoothing and UTC Generation (Demetrios Matsakis, USNO, USA)

**15:30 - 15:50**    *Tea / coffee break*

#### ***SESSION VII – NTP Algorithms***

<b>15:50</b>	<b>16:30</b>	<b>Invited talk - Poul-Henning Kamp “Improved NTP Timekeeping”</b>
<b>16:30</b>	<b>16:50</b>	An Auto-Regressive Moving-Average Time Scale Algorithm (ARMA) for Synchronizing Networked Clocks (Judah Levine, NIST, USA)

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